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NUCLEAR GENERATION PROGRAM

Report of Research Program
Advisory Committee No 5

Report No 85-164-K

job	file	date	report no.
740601-806-097	808.3503	June 3, 1985	85-164-K

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EXECUTIVE SUMMARY

NUCLEAR GENERATION PROGRAM

Report of Research Program
Advisory Committee No 5

The Nuclear Generation Research Program Advisory Committee (RPAC) is responsible for advising on long-term strategy options in the planning of Research Division's work programs in the Nuclear Generation Program area.

The 1985 review of the Nuclear Generation Program area concentrated on the identification of corporate needs, investigation of emerging program areas to address them, and identification of requirements for anticipatory research to meet corporate needs in the 0 to 20 year time frame. The Committee grouped the various research issues in the nuclear generation area into three sub programs: reactor systems; steam raising and handling systems; and general issues. Some key issues requiring further research work are: reactor rehabilitation; maintaining integrity of aging components and structures; development of generic capabilities; end-of-life assessment; load following; decommissioning; and safety assessment.

Research Division at present is involved in an undesirably high proportion of reactive research. The recommended strategy is that the Research Division, in addition to providing good service to its clients for short-term problems, should be involved in key Nuclear issues in an anticipatory manner so that capabilities and expertise will be available when needed in the future. As a number of emerging issues are specific to the CANDU system, the impact on Ontario Hydro's nuclear generation program, and indeed to pollution abatement program, is severe if such expertise and capabilities are not available. It is recommended that Research Division OM&A funding in the nuclear generation area should grow to assist in maintaining and improving the reliability, efficiency, and safety of our nuclear plants.

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To

Mr. F.J. Kee
Director of Research

NUCLEAR GENERATION PROGRAM
REPORT OF RESEARCH PROGRAM
ADVISORY COMMITTEE NO 5

1.0 INTRODUCTION

The Nuclear Generation Research Program Advisory Committee (RPAC) is responsible for advising on long-term strategy options in the planning of Research Division's (OHRD) work programs in the Nuclear Generation program area. A substantial part of OHRD's work programs at present are short-term in nature and are in response to the present problems of nuclear stations. The thrust of this report is to suggest that Ontario Hydro requires a greater effort in anticipatory R&D so that capabilities and expertise will be available when needed in the future. Since expertise specific to the CANDU system is not available anywhere else in the world, the impact on Ontario Hydro's nuclear generation program is more severe if such expertise and capabilities are not developed for Ontario Hydro's needs. Reductions in Ontario Hydro's nuclear generating capability adversely impact upon the cost of electricity and our commitment to reduce acid gas emissions. Increased anticipatory research will help in maintaining and improving the reliability, efficiency, accept-ability, and safety of our nuclear plants, which are expected to account for about 65 per cent of energy production in Ontario Hydro by 1993. The terms of reference, scope, and methodology used by the 1985 committee are detailed below.

1.1 Terms of Reference

The 1985 RPAC cycle differed from the previous ones/1/ in that the purpose of this year's study is to

(1) identify corporate needs and opportunities in the Nuclear Generation area in the 0 to 20 year time frame (1985 to 2005);

(2) identify existing or emerging program areas to address them; and,

(3) identify requirements for anticipatory research effort to meet corporate needs.

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There was no attempt to discuss in technical detail the various activities currently underway. The thrust was to look at the future to identify what will or could happen to Ontario Hydro's nuclear plants and what OHRD should be doing to meet future needs.

1.2 Methodology

Preparation of the 1985 RPAC report is largely based on 1984/85 RPAC Guideline/2/; the recently completed report "Scenarios for Research Planning" report/3/; the 1982 Nuclear Generation RPAC report/1/; Corporate strategy/4/; Ten Year Outlook reported to Board/5/; Ranking model/6/; and input gathered from senior design, operations, and research staff of Ontario Hydro. The Committee grouped the various research opportunities and issues into the following three areas:

1. Reactor Systems (Sub Program Area 51) - Section 4.0

2. Steam Raising and Handling Systems (Sub Program Area 52) - Section 5.0

3. General (Sub Program Area 50) - Section 6.0

Appendix I shows the topics included in these three sub program areas.

The relative importance of the opportunities and issues was then assessed using the ranking model and decision matrix developed by Floyd/6/ (see Appendix II for the criteria) and is reported in Section 7.2. The recommended strategy and possible impact of contingency events is discussed in Sections 7.1 and 7.3 of this report.

1.3 Scope

The report deals with the opportunities and issues related to the nuclear generation system and includes:

- the reactor, fuel, fuelling machines, primary heat transport system, fuel channels, and moderator system.

- steam generators, heat exchangers, turbines, structures and foundations, but not the generators or in-station electrical power systems.

- heavy water production and upgrading systems, in-station radioactive waste control, containment systems, irradiated fuel bays, tritium removal system, gas and liquid purification

systems, but not the off-site transportation or extended on-site storage of spent fuel.

The report also includes development and applications of new techniques to monitor or evaluate components, systems and materials in the nuclear power plants under various normal and abnormal operating conditions.

2.0 ACKNOWLEDGEMENTS AND CLIENT INPUT

As part of the process of compiling this report, inputs were sought from representatives of a number of other Divisions with responsibility for various aspects of the nuclear generation system. The committee wishes to recognize the contributions of senior staff from the following Divisions:

- Design & Development Division
- Generation Projects Division
- Technical & Training Services Division
- System Planning Division
- Economics & Forecasts Division
- Corporate Power System Program Division

Staff from these client Divisions, in general, agreed that a co-ordinated strategy to anticipate and minimize future problem areas would be very beneficial and cost effective. They provided valuable feedback on 1) scenarios and contingency events; 2) additional emerging issues and program areas; and 3) changes in priorities and ranking of work programs.

Additionally, inputs have been received and incorporated from a number of Research Division staff not on the committee who are involved with specialized studies having applicability to nuclear generation.

3.0 SCENARIOS - A VIEW OF THE FUTURE

3.1 Middle-of-the-Road Scenario

The scenario used in the preparation of this report is essential-the "middle-of-the-road" future outlined in the "Scenarios for Research Planning" report by Byrne, Hanson, and Watson/3/. This

"scenarios" report considers three time frames: 1983-1987, 1988-1992, and 1993-2002. For each time frame, economic and sociological factors such as average load growth, and the technological factors such as the impact of computers are considered.

The information presented in the above report was augmented by the "ten year outlook" presented to Ontario Hydro's Board of Directors/5/, the nuclear generation corporate planning assumptions document by M. Nichols/7/, and by the development of other planning assumptions by the nuclear generation RPAC. This Committee's view of the future was an important part of the deliberations and played a major role in the development of our recommendations.

Aspects of the "middle-of-the-road" scenario which are particularly relevant to this report are:

- In spite of the current excess generating capacity, technologies related to the supply side of Ontario Hydro's operation will continue to play a dominant part in the Research Division activities.

- Technological areas, concerned with the structural integrity of components and equipment used throughout the nuclear plant, will remain important for reasons of reliability and safety. Historically, Ontario Hydro's nuclear units have demonstrated a high level of in-service reliability. The current judgement is that even though some individual components have demonstrated low reliability, they will not result in system-wide sustained low reliability/7/.

- Load following by nuclear stations will be an area requiring increased attention.

- We must demonstrate safe irradiated fuel disposal for continued public support of nuclear generation.

One assumption not explicitly mentioned in the report, but which was included in the scenario of the future used for the preparation of this report, is the need to design and build a major nuclear station beyond Darlington 'A' within the 20 year time horizon of this report. The present judgement is that if a new CANDU station is committed in 1986-87, then it is likely to be of a Darlington design. However, if there are delays into the 1990's on commitment of the next nuclear station, then various options become possible.

3.2 Contingency Events

To provide the plans presented in this report with some flexibility, deviations from the middle-of-the-road scenario are included by considering some contingency events. The contingency events of most relevance to the nuclear generation area are:

1. A problem generic to nuclear generation causes the prolonged shut down of Hydro's nuclear generation.

2. The role of AECL is significantly reduced.

3. A major nuclear accident occurs.

4. Problems in the Middle East occur, disrupting oil supplies.

5. An opportunity to produce power for export occurs.

The implications of some contingency events on the work plans in the nuclear generation area are discussed further in Section 7.3.

3.3 Other Considerations

Ontario Hydro is the principal user of the CANDU system. For Ontario, the CANDU system is attractive because of indigenous uranium supplies which result in low cost and secure supply of electricity (to replace electricity from a Bruce reactor with coal-generated electricity costs in excess of $200,000 per day). However, unlike PWR's and BWR's, relatively little information on the long-term performance of the CANDU system can be obtained from anywhere else in the world. Hence, to protect Ontario Hydro's multi-billion dollar investment in CANDU stations, a high level of OHRD capability in the nuclear generation area will be required. Additionally, the number of CANDU reactors to be constructed over the next ten years is not sufficient to maintain the present nuclear industry and some sole supply manufacturers are already considering shut-down of their plants. Hence, Ontario Hydro may have to increase its involvement in the manufacturing industries and OHRD will have to increase its capabilities to provide the necessary services.

4.0 OPPORTUNITIES: REACTOR SYSTEMS - NUCLEAR GENERATION (Sub Program Area 51)

4.1 Present Status

There is a total of 20 CANDU reactor units at various stages ranging from operating to under construction within Ontario Hydro. OHRD currently maintains expertise in a broad spectrum of

technologies which are applied to reactor systems. There is a continued need to upgrade technology to provide "state-of-the-art" techniques to ensure that operating reactors continue to produce electricity in a safe, reliable and economic manner. The main research issues in CANDU reactor systems (Sub Program Area 51) at present are: understanding mechanisms of pressure tube failure at Pickering NGS 'A'; obtaining information on pressure tube creep and elongation; calandria tube integrity; large scale fuel channel replacement; spacer location and repositioning; effects of load following; and reactor safety.

4.2 Key Emerging Issues and Research Requirements

In the opinion of this RPAC, the key emerging issues requiring further research effort related to CANDU reactor systems (Sub Program 51) are as follows:

1. Reactor Rehabilitation

2. Load Following

3. Decommissioning

4. End-of-Life Assessment

5. New Stations and Upgrading of Existing Stations

6. Advanced Fuel Cycle

4.2.1. Reactor Rehabilitation:

For clarity of discussion, several of the programs such as LSFCR, REFAB, West Shift, and SLAR are grouped under the general heading of Reactor Rehabilitation. All the reactor rehabilitation programs require an assessment of the integrity (this includes potential for fracture and also deformation rates) of the pressure tubes and calandria tubes. This assessment must include pre- and post-rehabilitation conditions. Development of in-service inspection (ISI) and on-line monitoring techniques to monitor defects and structural integrity, locate garter springs, etc, is necessary. For removal and in-situ repair of components, development in the areas of electromagnetic techniques and robotics is required (robotics are also necessary for ISI).

For LSFCR the replacement pressure tubes will be Zr-2.5 wt% Nb, but modified production processes may be used which result in lower tube elongation rates.

Decontamination is a prerequisite for most major reactor rehabilitation efforts. Research is required to develop improved decontamination solvents, particularly for fuel debris dissolution. Rupture of a fuel bundle would result in widespread contamination by UO_2 fuel debris which is insoluble in presently available solvents. A dilute process for UO_2 dissolution should be developed.

4.2.2. Load Following:

The effects of reactor load following on the integrity of core components is unknown. Temperature and pressure cycles will be small in a load following operation and neutron flux cycles will vary in the range 60 - 100%. There is, however, a need to evaluate the influence of the cyclic operation on core component behavior. Also, the purification circuit and instrumentation and control equipment performance under load following conditions should be investigated. Vibration and dynamic behaviour of components under part load situation should also be investigated.

4.2.3. Decommissioning:

A review/8/ in 1981 recommended that a research program be undertaken to investigate system decontamination with more aggressive "metal dissolving" solutions. Also chemical and mechanical means to remove adherent radioactive materials from concrete surfaces, components, tools, etc, should be developed so that items can be disposed of as conventional scrap metal. Currently, decontamination of fuel baskets is underway and this may provide valuable information on decontamination procedures. Development of robotics is seen as important in decommissioning. Also, plasma arc melting, high energy lasers and electromagnetic techniques could play an important role in volume reduction of radioactive components.

4.2.4. End-of-Life Assessment:

All reactor components and systems require periodic evaluation and monitoring to forecast when they will reach or if they have reached end-of-life. Basically, two aspects need to be addressed: 1) will components and systems last for their design lives, and 2) will components and systems be able to continue operation past their design lives, ie evaluate residual life. These programs require continual upgrading of materials testing and also station monitoring capabilities, particularly continuous on-line surveillance and recording techniques.

4.2.5. New Stations and Upgrading of Existing Stations:

Currently, there is a study to evaluate the potential for a new fuel channel design. If a new design concept is recommended and accepted, then a number of tests and evaluations of the new design will be required. The potential to produce zirconium depleted of the high neutron-absorbing isotope ^{91}Zr is currently being evaluated. If such zirconium is available for the manufacture of core components, then a number of potential benefits could arise.

Research is required to develop a better understanding of the chemistry of CANDU reactor circuits such as the PHT, moderator, end shield cooling, annulus gas, recirculating cooling water, etc. The chemistry in these systems should be characterized with regard to the species present and interactions with system materials under both normal and fault conditions. Optimum operating values of chemical parameters should be determined and improved control measures investigated. PHT and moderator system chemistry control depend mainly on ion exchange resins. Application of electrodialytic decontamination of spent resins should be investigated in order to reduce the volume of high-activity resin waste produced.

Developments in on-line vibration and structural integrity monitoring techniques should continue and should be used on new as well as existing stations as a predictive tool and also as an aid in planned maintenance resulting in an extension of station life. Developments in dynamic fluid flow analysis for design of new stations could eliminate a number of flow-induced vibration problems which eventually cause damage to components.

Improved flow measurements in the PHT system are required. Developments in laser and fibre optic measurement techniques may be useful. This would result in improved efficiency as operating margins would be able to be reduced while safety margins will be maintained. Such flow measurement techniques may be retro-fitted to operating stations.

4.2.6. Advanced Fuel Cycle:

Advanced fuels including low enriched uranium (LEU) and Pu/U and Th are being considered and could be used in future stations. Ontario Hydro is participating in the Recycle Assistance Program to develop reprocessing and high level liquid waste treatment processes. Present major work areas under the program include reactor physics assessment, amine process waste management evaluation, by-product separation, off-gas treatment and use of lasers (already mentioned in Decommissioning) for fuel decladding. Other studies such as review of the amine process and identification of

the most promising improvements to the Purex process have recently been proposed.

5.0 OPPORTUNITIES: STEAM RAISING AND HANDLING SYSTEMS - NUCLEAR GENERATION

This program area deals with the equipment in the steam/water or secondary system. For the purposes of the RPAC program, the program area also includes all heat exchangers in the CANDU reactor system (eg moderator, end shield cooling, shutdown cooling, etc). The rationale for this is that many of the material degradation issues in these heat exchangers are closely related to those in steam generators and secondary system heat exchangers, despite the wide differences in operating conditions.

5.1 Present Status

The secondary circuit of a nuclear reactor is also called the "conventional side", a reflection of the fact that this circuit is not fundamentally different from the steam/water system of a fossil-fired generating station. Thus it can be expected that many of the problems and issues encountered with the components will be similar also. Although there are indeed many common areas, there are also some fundamental differences. The most important of these is the design of the nuclear steam generator which is very different from that of a fossil boiler. Temperatures, pressures, and steam quality in nuclear secondary systems are generally lower than in fossil-fired stations, and other components differ considerably in design, performance, and materials of construction. In addition, there are significant radiation fields in the vicinity of nuclear steam generators. Thus, many of the issues associated with operation of the "conventional side" are unique to nuclear plants. Also, because of differences in secondary system design and materials between our various stations, many of the issues confronting Ontario Hydro are plant-specific.

There is a broad range of activities underway at Research Division addressing problems associated with the operation and maintenance of the secondary system. The main issues (other than routine maintenance problems) which presently face Ontario Hydro's secondary system are:

- steam generator tube integrity; failures in the Bruce U-bend region and potential degradation under sludge piles; overall, Ontario Hydro tube performance has been excellent compared to extensive worldwide failures in Inconel 600 tubes;

- heat exchanger incapability, primarily due to an unexpectedly high incidence of tube failures in a number of heat exchangers cooled by lake water on the shell side;

- potential for failure of turbine rotors due to disc stress corrosion cracking;

- main steam line degradation mechanisms, eg vibration-induced fatigue;

- condenser leakage at Pickering, causing ingress of impurities into the condensate/feedwater system.

5.2 Key Emerging Issues & Research Requirements

The following three key emerging issues have been identified for anticipatory research in the steam raising and handling systems of CANDU stations.

1. Integrity of aging secondary system components.

2. Effects of load-following on secondary system components.

3. New materials and designs.

5.2.1 Integrity of Aging Components

a) Steam Generators

Maintaining steam generator (SG) integrity in nuclear plants as they age is of vital importance to plant reliability. Tube integrity should be the main focus of the work. The excellent performance to date of Ontario Hydro's tubes, while encouraging, does not provide an assurance of continued reliability, particularly in view of the poor world wide experience. Severity of problems is expected to increase with plant age as different degradation mechanisms may become important. Furthermore, since the primary coolant in a CANDU reactor is heavy water, tolerable leakage rates are much lower than those in LWR's.

Programs should be undertaken to anticipate what can happen to steam generator tubes to compromise their integrity, to develop means of preventing these events where possible, and to develop methods of detecting and repairing the damage. The work program should include the following:

Definition of potential failure mechanisms: Laboratory studies are required to define the major degradation mechanisms of the tube alloys used in our SGs. This includes a

study of environmental fracture phenomena (fatigue, stress corrosion), under-deposit corrosion mechanisms (cracking, pitting and wastage), flow induced vibration-related failures, and possibly other mechanisms.

In-Situ Measurements and Modifications: Improved NDE methods should be developed for detection of degradation of steam generator tubes, particularly under sludge piles or near support structures. Material thermomechanical treatment and stress condition are important factors in determining the potential for environmental fracture and corrosion. In-situ stress measurements should be carried out to complement the laboratory work on environmental fracture. Work should be undertaken into methods of altering stress levels or material properties in-situ in operating SGs. Techniques such as in-situ stress relief, surface peening (to impart compressive surface stresses) and SG structural modifications should be investigated. It is acknowledged that such modifications may be very difficult to implement.

Deposit Prevention or Removal Techniques: Methods should be developed to minimize the degree of deposit formation in SGs or to modify deposit properties. Alternative feedwater chemical treatment may minimize feedwater system corrosion, reduce the tendency of the corrosion product particles to deposit in the SG or beneficially alter the properties of the sludge deposits. The development of sludge pile removal techniques (water-jetting, chemical cleaning) should be completed and alternative means explored. Chemical or mechanical methods of removing deposits from crevices at support structures should be developed. The effect this will have on tube/support plate interactions (such as fretting or impact damage) is not well understood and should be studied.

Leak Detection and Propagation: New or improved leak detection methods should be developed in order to reduce outage times. Techniques should be developed to enable prediction of growth rates of tube leaks for various defect types and degradation mechanisms. Research is required to define the conditions under which SG tube failures can produce very large primary-to-secondary leaks. SG tube crack orientation and propagation behavior should be characterized. Potential sources of loose objects in SGs should be examined and monitoring techniques developed. Cascading effects on adjacent tubes from a complete tube fracture should be assessed.

Repair and Replacement of SGs: Studies should be undertaken into methods of SG tube repair and complete SG replacement. Tube staking and stabilization techniques should be studied

and the long term integrity of stabilized tubes confirmed. Tube sleeving techniques should be developed for 13 mm CANDU SG tubes and novel electromagnetic methods for SG rehabilitation should be investigated. Techniques required for complete steam generator replacement, such as automated welding, should be identified, developed and tested.

b) Heat Exchangers:

Problems with heat exchangers (HXs) account for a substantial portion of the recent downtime at Ontario Hydro nuclear generating stations.

The principal reasons for failures in HXs cooled by lake water have been under-deposit corrosion and flow-induced vibration problems. Laboratory and field research is required to understand the fundamental causes and nature of these degradation mechanisms. Fouling of HX and condenser tube surfaces can greatly increase the susceptibility of these components to failure via under-deposit corrosion. Research is required to determine the role of micro-organisms in the formation of fouling deposits (including both organic slimes and inorganic precipitates) and the corrosion mechanisms which may take place under the deposits. More effective and environmentally acceptable (for once-through cooling systems) methods to control biofouling and biocorrosion should be investigated.

HXs such as feedwater heaters, reheaters and preheaters operate at generally higher temperatures than the HXs discussed above, and the problems which they encounter are more like those of SGs, eg SCC, corrosion fatigue. In those cases where adequate information is not available (eg Bruce NGS preheaters), a program analogous to that proposed for SGs should be carried out.

c) Turbines:

Conditions and mechanisms which may lead to turbine component failure should be characterized where these are not known from external or fossil-fired experience. Fracture mechanics techniques should be employed to predict rotor life. Crack initition and growth should be studied experimentally. In-situ monitoring of rotor stresses, bearing condition and blade erosion should be carried out to anticipate problems in these areas. Development of hard-facing alloys and techniques for applying them should be undertaken to facilitate blade repair procedures.

5.2.2 Effects of Load-Following on Secondary System Components

There is no significant experience worldwide with load-following by nuclear power reactors, although the French and Germans have demonstrated the load-following capabilities of their PWRs. The assumption that there will be increasing failures of secondary side components in this mode of operation is based in part on the observation of the reduced reliability of two-shifted thermal plants.

Load-following will have the effect of causing a major increase in the number of temperature/pressure/flow rate cycles that are experienced by the system components compared to base-load operation. This will have direct effects on system integrity by imposing frequent cyclic stresses on system components. Part load operation can result in vibration problems as well. There may be indirect consequences also, for example the increased accumulation of deposits in SGs resulting from frequent feedwater transient conditions.

Work should be undertaken to determine the implications of load-following on critical secondary side components, particularly on SGs and turbines. The effect of the load cycling on the initiation and propagation of the possible degradation mechanisms should be examined.

5.2.3 New Materials and Designs

Research should be undertaken to investigate new materials and designs for secondary system components. The need for these will stem from two sources. A new nuclear generating station may be built as early as 2000 and appropriate materials will be required. At existing generating stations, component failures will require the fabrication of replacement items and upgraded materials may be required. It is recognized that the principal responsibility for system design and retrofitting resides outside of OHRD, and that our role is, therefore, likely to be participation in (as opposed to leadership of) the overall design effort.
Examples of areas in which anticipatory research efforts should be carried out include:

Identification and evaluation of new materials (or treatments) for HX tubes in contact with lakewater.

Evaluation of present and potential alternative SG tube materials (and tube conditions) for post-Darlington use or for replacement of present SGs should this be required.

Evaluation of design changes to secondary side components to minimize or avoid present problems in post-Darlington reactors.

Assessment of advanced materials and application techniques (eg hard-facing alloys, ion implantation, amorphous alloys) for use in secondary side components.

In addition to these specific areas cited, it is likely that much of the work in section 5.2.1 directed towards maintaining the integrity of our present plants will be relevant to the specification of new materials and designs for future components.

6.0 OPPORTUNITIES: GENERAL ISSUES - NUCLEAR GENERATION (Sub Program Area 50)

In this section, nuclear generation issues other than those presented in sections 4.0 (Reactor Systems) and 5.0 (Steam Raising and Handling Systems) are covered.

6.1 Present Status

Most of the emerging issues listed in the following sections are already in the initial evaluation stage. Some relatively short-term research areas are well under way, but may lead to additional, longer term work. Examples include materials characterization for tritium service, hydrogen separation technology and the detection of leaks from containment areas. Other technologies such as analytical chemistry services are continually evolving and cannot be considered to belong to any particular time frame.

6.2 Key Emerging Issues and Research Requirements

The following key emerging issues have been identified as requiring anticipatory research:

1. Generic Capabilities in Structural Integrity Evaluation

2. Safety Studies

3. Instrumentation and Control

4. New Business Ventures

6.2.1 Generic Capabilities in Structural Integrity Evaluation

The Division's capabilities in the areas of non-destructive evaluation, fracture mechanics, experimental and theoretical stress analysis, and repair methods, such as welding technology

and electro-magnetic techniques, should be developed since these techniques are of importance in virtually all the material degradation issues.

The fall in cost of computing power should allow more intensive elastic-plastic stress and fracture mechanics analyses. More accurate models of creep, creep-fatigue, stress corrosion cracking and other failure mechanisms would be possible.

Residual stress determination in existing equipment and structures is an important factor in structural integrity and other assessments. Techniques for residual stress measurements using X-ray diffraction, neutron diffraction, and magneto-elastic and optical strain gauges need to be developed or obtained from outside sources.

Advances in microelectronics and in other areas should continue to influence the development of non-destructive evaluation methods. Specifically, robotics would allow the development of devices for delivery of instrumentation packages to hazardous locations. Sensors which are stable in high radiation and high temperature environments should be developed for on-line monitoring of structural integrity.

Emerging areas in concrete technology include behavior under extreme loads due to LOCA or seismic events, and inspection and repair techniques following such events. Non-linear stress analysis should be developed as a tool in this area. In the longer term, attention should be given to aging, and remedial measures and retrofitting techniques on mature concrete structures.

Detailed material data will continue to be required for reactor safety analyses and structural integrity assessments. In view of the increasing number of operating CANDU units and the diversity of materials in use both in Ontario Hydro and externally, data bases of material/design/environment information and interactions between them should be established. Operating experience available from Operations and Design Departments should be included in the data bases. As the nuclear plants age, there will be an increase in the number and in the activity level of the samples that will require examination. The Division's capability for handling radioactive materials should be increased to satisfy this need.

6.2.2 Safety Studies

The primary responsibility for safety related studies lies with the Nuclear Studies and Safety Department (NSSD) of the Design & Development Division. Research Division has worked co-operatively with NSSD and it is hoped that this co-operation will increase significantly in the future. Some areas of possible Research Division involvement are as follows:

Studies are required to assess the effects of certain postulated accident scenarios on component integrity and radionuclide release. To verify licensing codes, an extensive program to characterize pressure tube deformation under LOCA scenarios is underway.

Studies are required to characterize performance of mechanical components such as pumps and seals under abnormal conditions of operation. Other areas requiring attention include studies related to determining load carrying capabilities of a square reactor vault, studies related to performance and integrity of vacuum building components, some reactor thermal hydraulic studies and effects of excessive vibration on component integrity. Studies related to steam generator integrity during severe transients should be initiated in collaboration with NSSD. This could include response of steam generator to rapid system depressurization and injection of cold water via the emergency boiler cooling system, and the studies related to the effects of the transients on partially degraded tubes or support structures.

New techniques for detecting and locating leaks from containment areas should be developed. Candidate technologies include ultrasonic and tracer gas methods. The planned vacuum building outages should provide opportunities for further studies into long-term behavior of CANDU multi-station containment integrity.

Recently developed processes for carbon-14 removal should be implemented in operating nuclear stations. Processes for detritiation of air based on microbial processes or super efficient drier columns should be investigated. With the advent of the Darlington Tritium Removal Plant, it may become necessary to develop tritium monitors which can distinguish between oxidized, organic, and elemental tritium in air.

6.2.3 Instrumentation and Control

Increased on-line monitoring of chemical or mechanical parameters could provide major cost effective benefits in CANDU systems. Development of this capability will require development of appropriate sensors, and also advanced systems for signal transmission

such as multiplexed digital signal transmission and/or fibre optics as a possible cost reduction area. Developments in post LOCA instrumentation is another area which will require attention in the future.

With increases in low-cost computing power, "expert systems", which mimic the actions of a human expert in assimilating data, drawing inferences and reaching conclusions, are expected to grow in importance. Such "expert systems" should be investigated as the basis for an intelligent control room for nuclear stations which as well as reporting information can assist the operator by suggesting the cause of unusual conditions and possible remedial courses of action.

6.2.4. New Business Ventures

The use of photochemical and microbial processes for the concentration and/or extraction of valuable radionuclides from spent fuel should be investigated.

Moving bed, gas chromatographic and laser methods of tritium separation should be investigated. These methods may provide cost effective alternatives to cryogenic distillation for later tritium removal plants. In addition, these developments may lead to lateral business opportunities through either the sale of the isotopes themselves or the sale of technology for isotope separation.

As the largest CANDU owner and user, Ontario Hydro has a wealth of experience and expertise, particularly, in reactor rehabilitation which could be marketed to other CANDU owners. With the possible reduced role of AECL in the future, this could represent a sizable business opportunity to Ontario Hydro.

7.0 DISCUSSION

7.1 Priorities and Strategy

The recommended research efforts in the various key emerging program areas and issues in nuclear generation have been outlined in sections 4.2, 5.2, and 6.2. Table I shows priorities of these programs over time frames of 0-5, 5-10, and 10-20 years. The time frame in this Table refers to the time when research work is required and not when the results are required. The priority refers to the importance of the program to the Corporation.

OHRD at present appears to have a rather high content of reactive research in response to short-term station problems. This is partly because OHRD, to meet its budget, has to rely on transfer

TABLE I

PRIORITIES OF RECOMMENDED RESEARCH PROGRAMS

	Priority (High, Medium, Low) of Research During Time Interval (in years)		
	0-5	5-10	10-20
(A) REACTOR SYSTEMS			
1. REACTOR REHABILITATION			
LSFCR	H	H	H
REFAB	H	H	L
West Shift	H	L	L
SLAR	H	M	L
2. Load Following	M	H	L
3. Decommissioning	L	M	M
4. End-of-Life Assessment	M	M	H
5. New Stations and Upgrading	M	M	H
6. Advanced Fuel Cycles	L	L	M
(B) STEAM RAISING AND HANDLING SYSTEMS			
1. Integrity of Aging Components			
Steam generators	H	H	H
Heat Exchangers	H	H	M
Turbines	H	M	M
2. Load Following	M	H	L
3. New Materials & Designs			
HX and SG Tube Materials	H	M	M
Advanced Materials	L	M	M

TABLE 1 (Continued)

PRIORITIES OF RECOMMENDED RESEARCH PROGRAMS

	Priority (High, Medium, Low) of Research During Time Interval (in years)		
	0-5	5-10	10-20
(C) GENERAL ISSUES			
1. Generic Capabilities Development			
NDE, Stress & Fracture Mechanics, Weld Repair	H	H	M
Concrete Technology	H	H	H
Material Properties Data Bases	H	H	H
2. Safety	H	H	H
3. Instrumentation & Control			
On-Line Monitoring	H	H	H
"Expert Systems"	L	M	M
4. New Business Ventures			
Recovery of Valuable Nuclides	L	L	L
Tritium Separation Technology	M	M	M
CANDU Expertise	M	M	M

funds which tend to be mainly available for reactive research programs. Anticipatory research with paybacks in 5-20 year time frame is frequently assigned a lower priority resulting in capabilities and technologies not being available when needed.

As a number of the key emerging program areas and issues discussed in the previous sections are specific to the CANDU system, very large cost savings to Ontario Hydro can be realized if such expertise and capabilities are available in advance. For example, in the case of the recent failure of G16 pressure tube in PNGS Unit #2, previous research work and capabilities on pressure tube material behavior, electromagnetic research, vibration and NDE work, proved to be very valuable. The resulting savings to the Corporation were significant. Hence OHRD's efforts and discretionary funding in the nuclear generation area must continue to grow to protect Ontario Hydro's multi-billion dollar investment in nuclear generation. This increase in Research OM&A funding will allow OHRD to concentrate on high priority emerging program areas in the 5-20 year time frame. This in turn will allow OHRD to have a strategy in place which does not require immediate increases in OHRD resources after a problem such as the recent pressure tube problem at Pickering NGS 'A'. It should be recognized that OHRD probably has no option at present, but to perform current reactive programs on major issues, but attempts should be made from such studies to identify "before-the-fact" areas of potential concern in the continued operation of Ontario Hydro's nuclear stations.

The emerging program areas and issues presented in this report for further research work are based on the middle-of-the-road scenario. This approach embodies an optimistic philosophy that our choice of and priorities on various program areas is a proper one and that we will be doing anticipatory or exploratory research on the "right" things. For example, development of generic capabilities will find applications in the solution of problems in reactor system, steam-raising and handling system, and general system components. Hence, maintenance and development of in-house expertise in generic areas such as non-destructive evaluation, on-line monitoring methods, stress analysis, thermal hydraulics and fracture mechanics will allow Ontario Hydro to deal with both known and new issues in nuclear generation.

7.2 Ranking of Nuclear Generation Issues

The importance of various programs to the Corporation has been given by the priorities in Table I. Ranking describes the relative importance of these programs from OHRD's point of view. Committee members ranked the various key emerging issues

TABLE II

RANKING OF EMERGING ISSUES

1. Rehabilitation
2. Generic Capabilities
3. Integrity of Aging Secondary Side Components
4. Safety
5. Instrumentation and Control
6. End-of-Life Assessment
7. Load Following
8. New Stations and Upgrading of Existing Stations
9. New Materials and Designs
10. Decommissioning
11. Advanced Fuel Cycles
12. New Business Ventures

following the procedures recommended in "Opportunity Area Ranking Model for Use by the RPACs"/6/. Appendix II lists the criteria used. The twelve highest ranked issues are shown in Table II.

The Table reflects the current ranking of programs and we expect this to change within the 20-year time frame, eg Reactor Rehabilitation has a high research content in 0-10 year time frame, but this will decrease in the 10-20 year time frame. Maintaining integrity of aging secondary system components is assigned a high ranking mainly because of potential problems in steam generators. Failure of steam generator components has a major economic and safety implication. Even though steam generators in Ontario Hydro's system have an excellent performance record to date, this must be weighed against the worldwide record of failures. Development of generic capabilities is assigned a high ranking because this will allow Ontario Hydro to deal with both known and new issues in nuclear generation as and when they arise. The safety concerns are of great intrinsic importance to Ontario Hydro. The avoidance of catastrophic failures and the satisfactory performance of safety systems are essential to the physical integrity of the plant and to the public perception of nuclear power as a safe energy option. The reason for the high ranking of end-of-life assessment studies is because this program area includes the periodic assessment of the integrity of reactor systems and components. Load following of nuclear stations is ranked high because this mode of operation is already upon us and warrants some research effort. Studies related to new materials and designs are assigned a relatively lower ranking because of the uncertainty about the timing and type of nuclear stations beyond Darlington 'A'. New Business Ventures is assigned a low ranking because it is not in response to Ontario Hydro's core business and also because of the small research component.

7.3 Implications of Contingency Events

Contingency events of the type described in Section 3.1 may have a major effect on some of the work areas described in this report.

The discovery of a problem generic to CANDU reactors could lead to the prolonged shutdown of Ontario Hydro's nuclear generation. Demand for power will be met with thermal generation and purchases with an economic penalty in excess of $200,000 per day per reactor. A generic problem would result in OHRD being involved in reactive research to find a solution to the problem. Also some of the OHRD resources may be redeployed to ensure continuing reliability of fossil-fired stations required to replace the lost nuclear capacity. Prior in-house expertise in the areas of integrity of aging plant components, assessment of safety issues,

new materials and designs, and generic capabilities would be of significant benefit.

A reduction in the role of AECL would impact on the OHRD studies on reactor systems. OHRD will have to increase its capabilities to provide the necessary service to nuclear stations. Basically, OHRD would not have the resources or the capabilities to perform the required studies. This could mean that OHRD would be extensively involved with "off-shore" organizations to obtain access to hot cells and to monitor progress on contracted research. Another possible result of a decrease in federal support for AECL could be a policy decision on Ontario Hydro's part that some parts of AECL need to be protected from collapse. The effect of this may be the contracting to AECL of work that might otherwise be carried out at OHRD. A decision to assign some of this work to AECL would result in a net reduction of OHRD activities.

Events which could lead to an increase in load growth, such as problems in the Middle East disrupting oil supplies, or a change in the political climate encouraging Ontario Hydro to produce power for export, could result in the building of additional nuclear stations. This would provide opportunities for OHRD to identify and develop improved systems, materials, and monitoring techniques for use in new stations. Conversely, if load growth is low, Ontario Hydro's nuclear generating capacity could significantly exceed base load. The resulting extensive need to load follow will increase the importance of this program area

7.4 Opportunities for Interdisciplinary and Co-Operative Projects

Research on the key technology areas requires a significant allocation of staff and financial resources, and generally requires contributions from several disciplines. It is recommended that managers or co-ordinators be appointed on a project basis to ensure that effective use is made of these resources.

In view of the present staff limitations in OHRD and in the absence of any likelihood of future staff increases, several of OHRD's programs in nuclear generation should be co-ordinated with studies at AECL-RC and other nuclear laboratories such as at Canadian Westinghouse Co. Close co-ordination is presently used in the Pressure Tube Project and, to a certain extent, may be accomplished by OHRD representation on various CANDEV committees.

In addition, OHRD's activities in the nuclear generation area should be co-ordinated with those of Ontario Hydro's Design and Operations Departments, where appropriate. Seminars such as the CANDU R&D seminar at Alliston, Ontario are very beneficial in integrating nuclear generation R&D effort across the Corporation.

It is recommended that more seminars of this type be organized in the future and include working-level participants from all Divisions involved. Additional participation of OHRD in Working Parties, Task Groups, and Steering Committees is desirable. Co-operative efforts with external agencies such as EPRI, IREQ, and the universities should also be encouraged to provide us with direct access to a wider body of information as well as injecting fresh ideas and points of view into OHRD research programs.

8.0 SUMMARY AND RECOMMENDATIONS

Major issues which face the nuclear generation program area over the next 20 years have been identified. The report recommends that OHRD get away from its present undesirably high proportion of reactive research and that it should be involved in these programs in an anticipatory manner so that capabilities and expertise are available when needed in the future. The Design and Operations Departments engaged in the Nuclear Generation area have reviewed this report and are in general agreement with the research programs identified in this report. The clients agree that a co-ordinated strategy to anticipate and minimize future problems areas would be very beneficial and cost effective. To protect Ontario Hydro's multi-billion dollar investment in the Nuclear Generation area, it is recommended that the Research Executive have a strategy in place to ensure that the work outlined in this report gets done. The key recommendation in this regard would be to increase the allocation of OHRD OM&A funds in the Nuclear Generation area. The Committee feels that there must be a better way of deciding on priorities of research programs than on the basis of budgets or transfer revenue.

Jim Chadha

J.A. Chadha
Chairman
Nuclear Generation RPAC
for Committee members

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P. Spekkens (Vice-Chairman #52)
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C.J. Simpson
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M.P. Dolbey
J.W. Forest
K.D. Curtis
B. Mukherjee
D.B. Warr
N.S. D'Silva
M.T. Flaman

9.0 REFERENCES

1. R.G. Fleck, "Nuclear Generation - a report by Research Program Advisory Committee #5", OHRD Report #D82-5-R.

2. O.A. Kupcis, "1984 RPAC Guidelines"; January 18, 1984.

3. T.P. Byrne, W.G. Hanson, W. Watson, "Scenarios for Research Planning", OHRD Report #83-545-K, December, 1983.

4. Ontario Hydro, 1985 Corporate Work Program and Budget.

5. Ten Year Outlook Reported to Board, CAPSULE, January, 1985.

6. G.L. Floyd, "Opportunity Area Ranking Model for Use by RPACs," Memorandum, File 808.31, February 1, 1984.

7. M. Nichols, "Corporate Planning Assumptions - Nuclear Program, 1984-2019", Issued Feb, 1985.

8. S.H. Hawthorne, "Nuclear Station Decommissioning - Radioactive Waste Management", OHRD Report No 81-337-K.

9. S.J. Naqvi, "Fuel Recycle/Advanced Fuel Cycles Program", memorandum to T.J. Carter, February 14, 1985.

APPENDIX I

Topics Included in Sub-Program Areas

1.0 Sub-Program Area 51 (Fuels & Reactors)

1. Fuel Channels and auxiliary systems.

   . PT, CT, end fittings, garter springs, etc
   . moderator system
   . calandria
   . end shields
   . feeders
   . reactivity control mechanism

2. Fuel, fueling machine, and new fuel handling systems.

3. Primary Heat Transport System including PHT pumps, Piping, pressurized, and PHT system chemistry control and corrosion.

4. NDE.

5. "Structural Integrity" of reactor components including materials evaluation, stress analysis, fracture mechanics, on-line monitoring systems.

6. Reactor component aging and rehabilitation including REFAB and LSFCR.

7. Reactor component performance under "Load Following".

8. Research and Development into future plant and advanced systems including PT development and fuel reprocessing.

2.0 Sub-Program Area 52 (Steam Raising)

1. Steam generator and auxiliary systems

   . steam generator
   . preheater
   . steam drum
   . SG tubes
   . SG tube supports

2. Light water circuit including feed pumps, water chemistry control, and feed piping.

3. Steam circuit including steam piping, and reheaters.

4. Turbines.

5. All CANDU system heat exchangers including moderator, end shield cooling, and shut down coolers.

6. Steam raising system component aging and rehabilitation including in-situ repair methods.

7. Steam raising system component performance and structural integrity under "load following".

8. R&D into future plant and advanced systems including new designs of SG and heat exchangers.

3.0 Sub-Program Area 50 (General)

Note: In general, this Sub-Program Area covers everything not covered by Sub-Program Areas 51 and 52.

1. Development of new methods and techniques for assessing performance of materials, components, systems and structures, including new methods of structural integrity, seismic, 2 phase flow, and materials evaluation.

2. Reactor building, vacuum building, foundations, concrete control.

3. Auxiliary CANDU station systems (not covered by 51 and 52) such as service water system, condenser water system, D_2O production, collection and upgrading systems.

4. . Tritium removal system
. Non-TRS related tritium work

APPENDIX I (Continued)

5. Safety Systems
   Includes emergency power supply system, emergency water supply system, radionuclide control within the station, performance of components and structures under earthquakes and abnormal operating conditions.

6. Instrumentation and Control.

7. Decommissioning.

APPENDIX II

CRITERIA AND WEIGHTING FACTORS USED IN THE OPPORTUNITY AREA RANKING MODEL/6/

Criterion		Weighting Factor
1	Opportunity to Advance to State-of-the-Art	0.16
2	Opportunity to Improve Staff Expertise	0.12
3	Probable Deliverable Impact	0.11
4	Significance to System Operation	0.11
5	Potential Benefit to People of Ontario	0.11
6	Potential Level of Staff Interest in This Research Area	0.09
7	Opportunity to Move Into a New Area of Research for OHRD	0.09
8	Significance of Possible New Technology	0.07
9	Congruence with Corporate Strategy	0.07
10	Degree of Support from Upper Management	0.07
	Sum	1.0